Historic, Archive Document

Do not assume content reflects current scientific knowledge, policies, or practices.

aSD11
.A48
(copy 4)

l States
tment of
ılture

t Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-139

February 1983

Canopy Development in Lodgepole Pine: Implications for Wildlife Studies and Multiple Resource Management

Dennis M. Cole

USDA
AGRICULTURE LIBRARY
NOV 20 '85
CURRENT SERIAL RECORDS

THE AUTHOR

DENNIS M. COLE is a research silviculturist with the Silviculture of Northern Rocky Mountain Subalpine Forest Ecosystems Research Unit at the Forestry Sciences Laboratory, Bozeman, Mont. His studies have focused on lodgepole pine silviculture; particularly growth and yield relationships, culture of immature stands, and management of the species in the face of major insect and disease problems.

RESEARCH SUMMARY

This report describes how recently developed models of vertical crown development in lodgepole pine (*Pinus contorta* var. *latifolia*) can be used with existing data to facilitate studies of wildlife-forest cover relationships. Instructions are given for obtaining values of stand basal area and average height of dominant trees—from forest inventory data bases or resource aerial photographs, such as those maintained by the National Forest System—and for solving the crown models for stands where wildlife data are available or studies are planned. The report shows how linkage of the models with a computerized stand projection program provides values of present and future effects of alternative timber management prescriptions on several important components of wildlife cover—height to canopy, canopy depth, stand height, and canopy coverage. Beginning at age 20 years, it illustrates these stand effects at 10-year intervals for a duration of 120 years, for five widely different initial stand densities—each subjected to five typical timber management prescriptions. Results and future uses of the canopy models and stand projections including them are discussed in relation to some current concepts of managing thermal cover and the possibilities of refining these concepts.

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-139

February 1983

Canopy Development in Lodgepole Pine: Implications for Wildlife Studies and Multiple Resource Management

Dennis M. Cole

INTRODUCTION

Lodgepole pine (*Pinus contorta* var. latifolia) covers over 17 million acres in the Western United States and nearly three times that amount in western Canada. In the Western United States, 13 million of the 17 million acres are classified as "commercial forest lands" (U.S. Department of Agriculture 1972). This means the land is designated to receive management activities for producing and sustaining timber and other resource values. In a land area of this size, considerable opportunity exists to favor or discourage some resource values in relation to others. Wildlife is a good example of this in relation to timber management activities—some wildlife species are favored by a particular silvicultural activity, while others are disadvantaged. It is important to know much more about the effects of stand manipulations on wildlife than we currently do if we are to achieve better multiresource management of lodgepole pine forests.

Probably more attention has been given to the effects of timber management on big game than on other wildlife, but significant gaps exist in our knowledge of how big game respond to composition and structure of forests (Beall 1976), particularly in regard to winter habitat requirements (Thomas and others 1979). According to Thomas and others (1979), "Each winter range is different in its vegetative mosaic and the way it is used by the animals. The manager should study winter range carefully before deciding if and how to alter cover, particularly thermal cover." As an adjunct to studies of the wildlife behavioral relationships associated with cover versus noncover, the thermal aspects of cover, and the importance of cover juxtaposition on the land, I believe that more attention should be given to depth and position of stand canopies and to how they change with time in both managed and unmanaged forests.

The state-of-the-art in growth and yield simulation of even-aged forest stands now allows forecasts of canopy characteristics from stand parameters that are the objects of silvicultural manipulation. In a related paper (Cole and Jensen 1982), models were presented for describing vertical development of canopies in even-aged lodgepole pine stands. In that work, the rationale and methods used to develop and test the models were covered and examples were given of how the models could be used with computerized stand growth projection programs to preview crown and canopy development under different timber management prescriptions. Such information is of interest not only to big-game managers, but to researchers studying behavioral associations of such diverse wildlife forms as the grizzly bear[1] (*Ursus arctos horribilis*) and nongame birds and mammals.

The objective of this paper is to bring these models to the attention of researchers and managers in the wildlife and forestry disciplines for the following purposes: (1) to point out how they can be used with forest inventory data or data from aerial photos, as a scalar to interpret the data bases in terms of vertical canopy characteristics; (2) to suggest that the extent and duration of canopy position and depth should be tested for correlation with wildlife behavioral traits in general, and cover requirements of big game in particular; and (3) to illustrate and discuss how different management situations and thinning prescriptions influence vertical canopy development in comparison to natural stands.

EXCHANGE Rec'd

[1]Knight, Richard. Personal conversation. Bozeman, MT: U.S. Department of the Interior, National Park Service, Interagency Grizzly Bear Team; 1981.

NOV 13

THE CROWN MODELS

Estimating Dominant Crown Position of Stands

An interactive model has been developed (Cole and Jensen 1982) that relates average height to the base of the crowns of dominant trees (HBCD) with average height of the dominants (HD), and stand basal area (BA):

$$\widehat{HBCD} = [(1.0019 * e^{-\left|\frac{\frac{BA}{250} - 1.0}{0.716}\right|^{5.5}} - 0.0019) * (0.1492 * HD^{1.33})] * 0.9786^{2/} \quad [1]$$

where:

$\overline{HBCD}$ = 23.3 ft, R^2 = 0.82, and $S_{y \cdot x} \cong 5.2$ ft,

and limits are

$50 \leq BA < 250$, and $0 < HD < 120$.

Note: *The above and all following mathematical expressions were developed in English units; therefore, their solutions are correct only with the specified units of the English system. Tables of results are likewise presented in English units.*

This relationship is represented as a response surface in figure 1, and estimated values of HBCD generated from it for ranges of BA and HD are given in table 1.

The model (equation [1]) can be adjusted to data sets from other populations of lodgepole pine trees through a simple least squares fitting of model estimates to observed sample values of HBCD (forcing the regression through the origin) to obtain a least squares scaling coefficient (b_i) for each population:

$$b_i = \Sigma XY / \Sigma X^2$$

where

X = estimated HBCD according to equation [1], and

Y_i = actual HBCD from the pertinent data set.

The value of the coefficient (b_i) is used to scale estimates from equation [1] to local conditions as shown in equation [2]:

$$\widehat{HBCD}_i = \widehat{HBCD} * b_i. \quad [2]$$

Estimating Dominant Crown Depth of Stands

Equation [1] with [2] provides estimates of the average position (height above ground) of dominant tree crowns in even-aged lodgepole pine stands, as a function of stand density and average height of dominant trees. Average depth (length) of dominant tree crowns can be estimated for a stand, following estimation of HBCD, as the difference between the average height of dominant trees (HD) and HBCD. Although the position and depth of the dominant crown class does not indicate the total depth and position of the stand canopy, dominant crown parameters will probably be more effective than total canopy parameters as indicators of wildlife relationships, because the suppressed tree component of lodgepole pine stands has relatively little influence on the amount and distribution of overall canopy biomass (Gary 1976). This distinction is particularly important in the case of thinned lodgepole pine stands, which are best thinned from below, thereby removing (to varying degrees according to thinning intensity) the lower portions of the overall stand canopy.

[2]Least squares coefficient from fitting the hypothesized relation to the data from which it was partially derived.

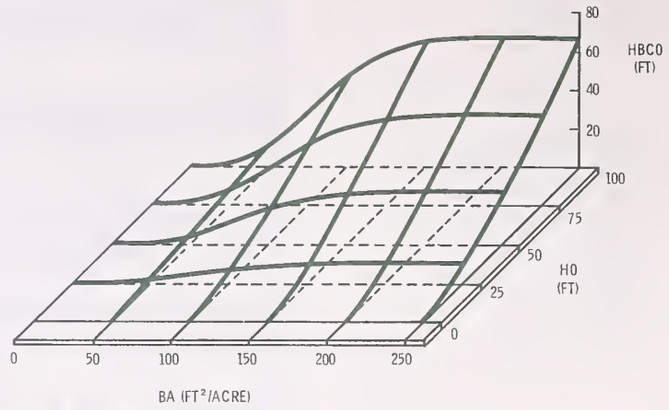

Figure 1.—Height to base of crown (HBCD) as a function of basal area per acre (BA) in square feet and average height of dominant trees (HD) in feet.

Table 1.— Height to base of crown (HBCD) in feet as a function of basal area per acre (BA) in square feet and average height of dominant trees (HD) in feet[1]

	BA						
HD	25	50	75	100	125	150	175+
10	–	–	1	2	3	3	3
20	–	1	3	5	7	8	8
30	–	2	6	9	12	13	13
40	1	3	8	14	17	19	20
50	1	4	11	18	23	25	26
60	1	5	14	23	29	32	34
70	1	7	17	28	36	40	41
80	1	8	20	34	43	48	49
90	2	9	24	40	50	56	58
100	2	10	28	46	58	64	66

[1]Values within the block fall within the range of the basic data.

Estimating Average Position and Depth of Stand Canopies

Despite the greater relevancy to this paper of the dominant portion of the canopy, estimates of the position and depth of the total canopy are possible because of the relationship (equation [3]) between average height to the base of crowns of suppressed trees (HBCS) and HBCD (Cole and Jensen 1982):

$$HBCS = -4.19 + 0.39\,HBCD + 0.18\,HD \quad [3]$$

$R^2 = 0.84$.

Equation [3] can be used, subsequent to estimating HBCD, to obtain an estimate of the position of the overall canopy in relation to height in feet above the ground. Overall depth of the canopy can be calculated then, as the difference between HD and HBCS for the stand.

CAPITALIZING ON EXISTING RESOURCE DATA

Many data bases already exist to which the equations reported in this paper can be applied. For example, all National Forest Regions maintain a timber management control system and periodically update aerial photography for each National Forest. These systems provide an inventory of the kind, amount, location, and status of the timber resource, and management and natural activities related to it. The Timber Stand Management Record System of USDA Forest Service Region One is a good example of how these systems work.[3] The Region One system is designed to:

a. provide information for silvicultural prescriptions,
b. plan for and schedule treatments,
c. make required reports,
d. keep an historical record of all treatments, and
e. provide information to update and revise the Timber Resource Plan and Harvest Schedule.

To accomplish this the system has three components:

a. index map,
b. stand folder, and
c. automated data base.

All components must be revised (and otherwise maintained) concurrently for the system to work correctly. The index map shows the boundaries of each identified stand in the record system, in relation to surrounding stands and the land base itself. The stand folder (one for each stand) contains all available information for managing the stand, and with reference to the other two components provides the basic data for making silvicultural prescriptions. The automated data base allows compilation and summarization of data obtained through stand examination surveys and other information filed in the stand folder and in return makes reports to the stand folder, thus updating the stand record.

The record system provides a means for accessing map-indexed values of HD and BA for all lodgepole pine stands entered in the system, where these values have been obtained in the stand examination survey. Using these values with the crown models reported here, the resource manager can revise the data base for all lodgepole pine stands to include the position and depth of the canopy for the dominant-tree portion as well as for the total stand canopy.

Not all lodgepole pine stands are yet entered in stand management record systems, and not all that are entered have dominant height and basal area values recorded. Most of the stands that have been entered into the system have been recorded because of a past management activity, such as harvesting or timber stand improvement that had created or modified the stand, or because such an activity was planned for the near future. However, the proportion of currently nonidentified stands should diminish rapidly in the next few years. This is because the National Forest Management Act requires that all timber management activities must be preceded by a silvicultural prescription that calls for that activity specifically or accommodates the activity naturally in the course of a larger prescription. Until all existing lodgepole pine stands are entered into the system and supported by stand examination data, including average height of dominant trees (HD) and stand basal area (BA), a supplemental source of information for these values is necessary. Controlled aerial photography can provide this alternative.

With the comprehensive and current aerial photo coverage available for all National Forests, lodgepole pine stands can be identified and delineated, and values of HD and BA can be determined photogrammetrically for any area in a National Forest. Thus, when the needed data on HD and BA are not available in the automated data base of the Timber Stand Management Record System, it can be obtained from available aerial photos for subsequent use in the crown models reported in this paper. These data and derived canopy estimates can also be added to the information in the stand folder of the Timber Management Record System.

BIG-GAME COVER CONCEPTS

Threshold values of area, canopy coverage, and attained height are the stand characteristics currently given greatest weight in attempts to define cover for mule deer and elk (Thomas and others 1979), and in attempts to determine the importance of cover to various habitat requirements of those species (fig. 2 and 3). For example, thermal cover for deer and elk is defined as a stand of coniferous trees 40 ft or more tall with average crown cover exceeding 70 percent (Black and others 1976). While these threshold values undoubtedly have some merit for discriminating between stands that do and do not provide suitable resting environments for summering elk and mule deer, they cannot provide a quantitative basis for further differentiating the thermal quality of summer environments—nor can they even identify winter thermal cover for elk.

Obviously, different silvicultural prescriptions create different stand conditions, which in turn can differentially influence the environments and behavior of wildlife. However, not enough is known about how specific silvicultural manipulations change stand structure and canopy characteristics—e.g., thermal aspects of the stands—and how these changes affect wildlife. Reifsnyder and Lull (1965) have compiled a thorough monograph on radiant energy in relation to forests. They discuss the components of radiant energy, the physical laws involved in the absorption and transmission of it in the forest, the measurement of these processes, and their general relationship with canopy components discussed in this paper. Workers interested in interpreting canopy values and changes in them, in terms of thermal implications, will find the Reifsnyder and Lull monograph a valuable reference.

Multistoried stands are considered better for cover than single-storied stands; however, if only single-storied stands are considered (as in this paper), dense stands with low canopies are better than lightly stocked stands with high canopies (Thomas and others 1979). These general concepts can be kept in mind as the reader examines the examples presented in the following section on the effect of some different lodgepole pine management prescriptions on canopy characteristics and timber size and yield.

[3] Timber Management Control Handbook, FSH 2409.21e, R-1 Amend. 9, 1980.

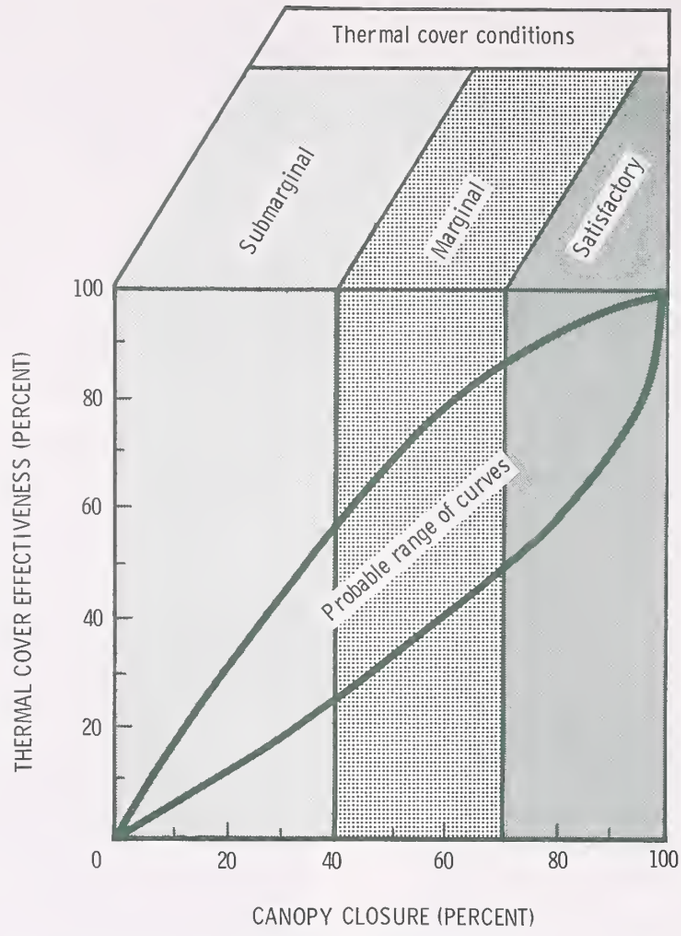

Figure 2.—Relationship of canopy closure to effectiveness of thermal cover for deer and elk (from Thomas and others 1979).

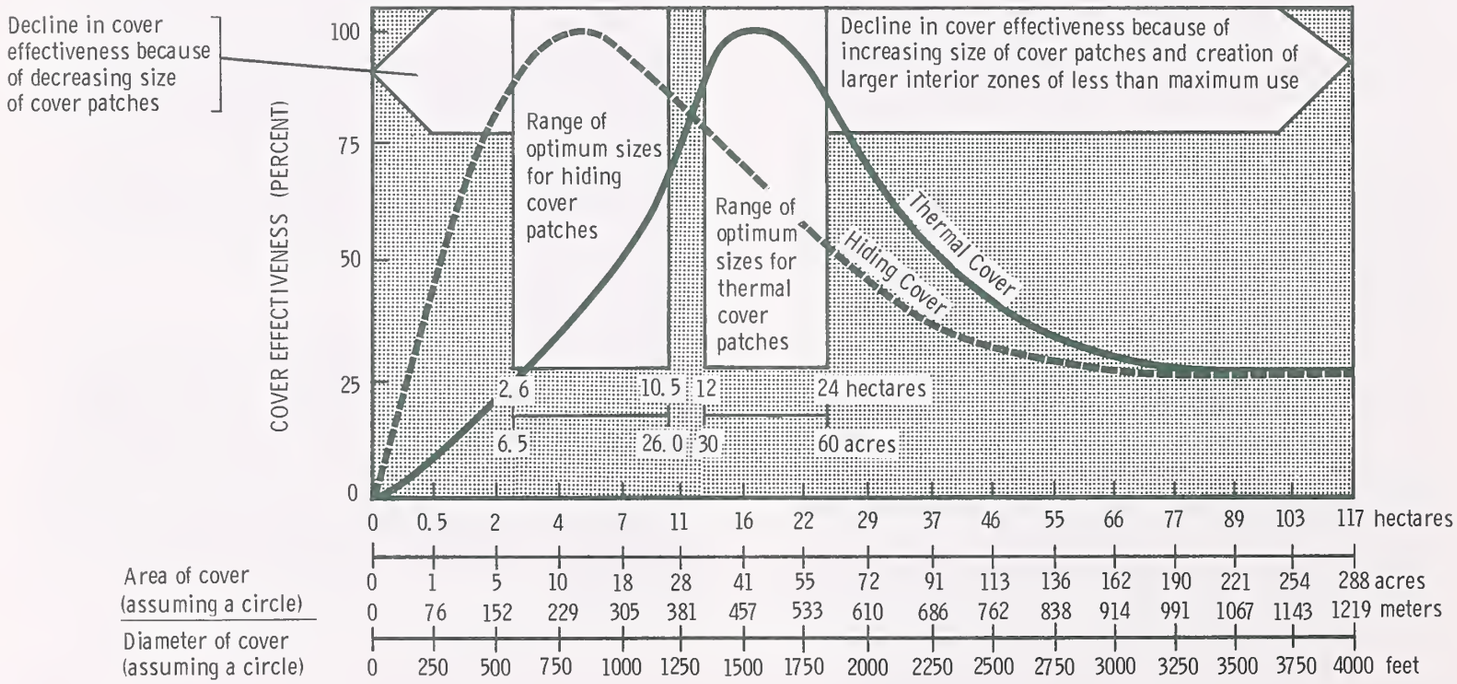

Figure 3.—Effectiveness of various sizes of hiding and thermal cover areas on summer and spring-fall ranges in the Blue Mountains. The range of optimum sizes for patches of hiding cover are derived from figure 60 in Thomas and others 1979.

FORECASTING COVER CHARACTERISTICS OF LODGEPOLE PINE STANDS

To estimate the vertical position and depth of stand canopies in the future, reliable estimates of dominant height (HD) and basal area (BA) must be possible for future ages. Realistic values of these parameters can be obtained with computerized tree and stand growth projections for lodgepole pine (Stage 1973; Myers and others 1971; Edminster 1978). The models reported here can also be imbedded in such computer programs to provide vertical crown development information in addition to other forecasts. We (Cole and Jensen 1982) did this with a stand projection computer program for lodgepole pine[4] (Myers and others 1971), modified to apply to development of natural as well as managed stands and to include growth equations developed from Montana and Idaho stand data (Cole 1971; Cole and Stage 1972; Stage 1975). In the Cole and Jensen paper, we give an example of vertical crown development, along with development of other important stand parameters for thinned versus unthinned stands of moderate and extreme initial stand densities.

In this paper, examples of projected canopy development for an increased number of management situations in lodgepole pine are shown (tables 2 through 6). Each table reflects the response of a specific stand density at age 20 years to several typical management prescriptions for lodgepole pine stands—as viewed through stand development to age 140 years. Although representative, these examples are only a small proportion of the large number of combinations of biological situations and management prescriptions that can be considered. The stand densities chosen were 500, 1,000, 2,000, 4,000, and 8,000 trees per acre at age 20 years. Five management situations were compared for each stand density:

[4]This program entitled "LP STAND GRO" is available from the author, upon request.

Table 2.— Lodgepole pine stand characteristics, from ages 20 to 140 years of initial stocking at age 20 of 500 trees/acre, under different management situations, on site index$_{100}$ = 60 lands in Montana and Idaho

Age	Management situation[1]	Number trees/ acre	Average stand diameter	Basal area	CCF	Average dominant height	Dominant crown height	Dominant crown length	Net merchantable volume[2]	Merchantable volume cut
Yrs			*Inches*	*Ft²*		*Ft*			*Ft³*	
20	N	500	3.2	28	48	15	1	14	—	—
	P	—	—	—	—	—	—	—	—	—
	P + C100	—	—	—	—	—	—	—	—	—
	P + C120	—	—	—	—	—	—	—	—	—
	DMT	333	2.7	13	26	14	1	13	—	—
50	N	483	6.0	95	110	34	10	24	1,090	—
	P	—	—	—	—	—	—	—	—	—
	P + C100	—	—	—	—	—	—	—	—	—
	P + C120	—	—	—	—	—	—	—	—	—
	DMT	327	6.7	80	88	34	8	26	1,020	—
80	N	435	7.4	130	137	48	22	26	2,480	—
	P	—	—	—	—	—	—	—	—	—
	P + C100	—	—	—	—	—	—	—	—	—
	P + C120	—	—	—	—	—	—	—	—	—
	DMT	290	8.3	109	110	48	19	29	2,150	—
110	N	372	8.6	150	149	60	32	28	3,750	—
	P	—	—	—	—	—	—	—	—	—
	P + C100	—	—	—	—	—	—	—	—	—
	P + C120	—	—	—	—	—	—	—	—	—
	DMT	200	9.5	98	94	56	22	34	2,340	—
140	N	307	9.6	154	147	69	39	30	4,550	—
	P	—	—	—	—	—	—	—	—	—
	P + C100	—	—	—	—	—	—	—	—	—
	P + C120	—	—	—	—	—	—	—	—	—
	DMT	118	10.5	71	66	59	22	37	2,340	—

[1]Management situation: N = no thinning, P = precommercial thinning at age 20 to growing stock level (GSL) 80 (Myers 1967), P + C100 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 100, P + C120 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 120, DMT = dwarf mistletoe-infected stand with dwarf mistletoe control thinning at age 20.
[2]Merchantable cubic feet is volume in trees 4.6 inches d.b.h. and larger, to 4.0-inch top.

Table 3.— Lodgepole pine stand characteristics, from ages 20 to 140 years of initial stocking at age 20 of 1,000 trees/acre, under different management situations, on site index$_{100}$ = 60 lands in Montana and Idaho

Age	Management situation[1]	Number trees/ acre	Average stand diameter	Basal area	CCF	Average dominant height	Dominant crown height	Dominant crown length	Net merchantable volume[2]	Merchantable volume cut
Yrs			*Inches*	*Ft^2*		*Ft*			*Ft^3*	
20	N	1,000	2.8	43	82	15	1	14	—	—
	P	457	3.3	27	46	16	1	15	—	—
	P + C100	457	3.3	27	46	16	1	15	—	—
	P + C120	457	3.3	27	46	16	1	15	—	—
	DMT	664	2.3	19	44	14	1	13	—	—
50	N	933	4.8	117	153	33	13	20	830	—
	P	441	6.2	92	102	35	10	25	1,140	—
	P + C100	327	6.6	78	86	35	10	25	1,010	130
	P + C120	412	6.3	89	101	35	10	25	1,120	20
	DMT	640	5.3	98	121	34	10	24	930	—
80	N	784	6.0	154	179	47	24	23	2,510	—
	P	399	7.7	129	129	49	23	26	2,570	—
	P + C100	227	8.8	96	94	50	21	29	2,010	340
	P + C120	301	8.2	110	112	50	23	27	2,250	240
	DMT	562	6.7	138	151	47	23	24	2,450	—
110	N	626	6.9	163	177	59	32	27	3,700	—
	P	343	8.9	148	148	61	33	28	3,810	—
	P + C100	157	10.8	100	92	62	29	33	2,690	450
	P + C120	224	9.9	120	113	62	31	31	3,160	290
	DMT	398	7.7	129	133	56	27	29	2,890	—
140	N	498	7.8	165	170	68	39	29	4,590	—
	P	284	9.9	152	152	70	40	30	4,590	—
	P + C100	142	12.2	115	102	71	35	36	3,620	—
	P + C120	196	11.1	132	120	71	38	33	4,060	—
	DMT	234	8.5	92	92	59	27	32	2,890	—

[1]Management situation: N = no thinning, P = precommercial thinning at age 20 to growing stock level (GSL) 80 (Myers 1967), P + C100 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 100, P + C120 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 120, DMT = dwarf mistletoe-infected stand with dwarf mistletoe control thinning at age 20.

[2]Merchantable cubic feet is volume in trees 4.6 inches d.b.h. and larger, to 4.0-inch top.

Table 4.— Lodgepole pine stand characteristics, from ages 20 to 140 years of initial stocking at age 20 of 2,000 trees/acre, under different management situations, on site $index_{100}$ = 60 lands in Montana and Idaho

Age	Management situation[1]	Number trees/ acre	Average stand diameter	Basal area	CCF	Average dominant height	Dominant crown height	Dominant crown length	Net merchantable volume[2]	Merchantable volume cut
Yrs			*Inches*	*Ft^2*		*Ft*			*Ft^3*	
20	N	2,000	2.4	63	137	14	1	13	—	—
	P	473	3.1	25	44	16	1	15	—	—
	P + C100	473	3.1	25	44	16	1	15	—	—
	P + C120	473	3.1	25	44	16	1	15	—	—
	DMT	1,392	2.0	30	79	13	1	12	—	—
50	N	1,525	3.9	127	189	31	12	19	—	—
	P	458	6.1	93	107	35	10	25	1,130	—
	P + C100	332	6.5	77	85	36	10	26	990	140
	P + C120	412	6.3	89	101	35	10	25	1,120	10
	DMT	1,007	4.3	102	142	32	10	22	—	—
80	N	1,163	5.0	159	203	45	23	22	1,810	—
	P	415	7.5	127	133	49	23	26	2,520	—
	P + C100	227	8.8	96	94	50	22	28	2,020	370
	P + C120	301	8.2	110	112	50	23	27	2,270	230
	DMT	748	5.7	133	158	45	21	24	1,920	—
110	N	888	5.9	169	197	57	31	26	3,280	—
	P	358	8.7	148	146	61	33	28	3,800	—
	P + C100	157	10.8	100	92	63	29	34	2,700	450
	P + C120	224	9.9	120	113	62	32	30	3,180	290
	DMT	499	6.7	122	134	52	24	28	2,410	—
140	N	681	6.8	172	188	66	38	28	4,370	—
	P	298	9.7	153	145	70	40	30	4,620	—
	P + C100	142	12.2	115	102	72	35	37	3,630	—
	P + C120	196	11.1	132	120	71	38	33	4,080	—
	DMT	293	7.6	92	96	56	24	32	2,410	—

[1]Management situation: N = no thinning, P = precommercial thinning at age 20 to growing stock level (GSL) 80 (Myers 1967), P + C100 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 100, P + C120 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 120, DMT = dwarf mistletoe-infected stand with dwarf mistletoe control thinning at age 20.
[2]Merchantable cubic feet is volume in trees 4.6 inches d.b.h. and larger, to 4.0-inch top.

Table 5.— Lodgepole pine stand characteristics, from ages 20 to 140 years of initial stocking at age 20 of 4,000 trees/acre, under different management situations, on site index$_{100}$ = 60 lands in Montana and Idaho

Age	Management situation[1]	Number trees/ acre	Average stand diameter	Basal area	CCF	Average dominant height	Dominant crown height	Dominant crown length	Net merchantable volume[2]	Merchantable volume cut
Yrs			*Inches*	*Ft^2*		*Ft*			*Ft^3*	
20	N	4,000	1.6	56	183	12	1	11	—	—
	P	539	2.3	16	35	15	1	14	—	—
	P + C100	539	2.3	16	35	15	1	14	—	—
	P + C120	539	2.3	16	35	15	1	14	—	—
	DMT	3,037	1.3	28	117	11	1	10	—	—
50	N	3,050	3.0	150	271	29	12	17	—	—
	P	523	5.7	93	110	35	10	25	1,050	—
	P + C100	349	6.2	73	84	36	10	26	920	130
	P + C120	433	6.0	85	99	36	10	26	1,030	20
	DMT	2,233	3.1	117	206	30	11	19	—	—
80	N	2,131	3.9	177	264	44	22	22	—	—
	P	472	7.1	130	139	50	23	27	2,510	—
	P + C100	239	8.5	94	94	50	21	29	1,970	350
	P + C120	312	8.0	109	111	50	23	27	2,230	270
	DMT	1,255	4.3	127	177	43	19	24	—	—
110	N	1,455	4.8	183	239	55	30	25	2,240	—
	P	403	8.3	151	152	61	33	28	3,850	—
	P + C100	163	10.6	100	92	63	30	33	2,710	480
	P + C120	232	9.7	119	113	62	32	30	3,160	300
	DMT	742	5.4	118	145	51	23	28	1,800	—
140	N	1,028	5.7	182	217	64	37	27	3,840	—
	P	332	9.3	157	151	70	41	29	4,700	—
	P + C100	147	12.0	115	103	72	35	37	3,640	—
	P + C120	204	10.9	132	121	71	38	33	4,100	—
	DMT	436	6.3	94	107	55	23	32	1,860	—

[1]Management situation: N = no thinning, P = precommercial thinning at age 20 to growing stock level (GSL) 80 (Myers 1967), P + C100 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 100, P + C120 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 120, DMT = dwarf mistletoe-infected stand with dwarf mistletoe control thinning at age 20.

[2]Merchantable cubic feet is volume in trees 4.6 inches d.b.h. and larger, to 4.0-inch top.

Table 6.— Lodgepole pine stand characteristics, from ages 20 to 140 years of initial stocking at age 20 of 8,000 trees/acre, under different management situations, on site index$_{100}$ = 60 lands in Montana and Idaho

Age	Management situation[1]	Number trees/ acre	Average stand diameter	Basal area	CCF	Average dominant height	Dominant crown height	Dominant crown length	Net merchantable volume[2]	Merchantable volume cut
Yrs			*Inches*	*Ft*^{2}		----------	*Ft*	----------	----------	*Ft*^{3} ----------
20	N	8,000	1.4	86	327	10	2	8	—	—
	P	539	2.3	16	35	14	2	12	—	—
	P + C100	539	2.3	16	35	14	2	12	—	—
	P + C120	539	2.3	16	35	14	2	12	—	—
	DMT	8,000	1.4	86	327	10	2	8	—	—
50	N	5,664	2.4	178	389	26	11	15	—	—
	P	523	5.7	93	110	34	10	24	1,010	—
	P + C100	349	6.2	73	84	35	10	25	890	120
	P + C120	433	6.0	85	99	34	10	24	990	20
	DMT	1,254	1.6	18	57	23	11	12	—	—
80	N	3,281	3.3	195	327	41	20	21	—	—
	P	472	7.1	130	139	48	23	25	2,450	—
	P + C100	239	8.5	94	94	49	21	28	1,930	340
	P + C120	312	8.0	109	111	49	22	27	2,180	260
	DMT	908	4.3	92	128	38	11	27	—	—
110	N	1,998	4.2	192	273	52	28	24	—	—
	P	403	8.3	151	152	60	33	27	3,780	—
	P + C100	163	10.6	100	92	62	29	33	2,660	480
	P + C120	232	9.7	119	113	61	31	30	3,100	290
	DMT	778	5.7	138	164	48	24	24	2,170	—
140	N	1,324	5.1	188	237	61	35	26	3,080	—
	P	332	9.3	157	151	69	40	29	4,630	—
	P + C100	147	12.0	115	103	71	34	37	3,580	—
	P + C120	204	10.9	132	121	70	38	32	4,030	—
	DMT	519	6.7	127	140	54	26	28	2,610	—

[1]Management situation: N = no thinning, P = precommercial thinning at age 20 to growing stock level (GSL) 80 (Myers 1967), P + C100 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 100, P + C120 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 120, DMT = dwarf mistletoe-infected stand with dwarf mistletoe control thinning at age 20.

[2]Merchantable cubic feet is volume in trees 4.6 inches d.b.h. and larger, to 4.0-inch top.

1. N = natural stand development of dwarf mistletoe-free stands,

2. P = precommercial low thinning[5] of dwarf mistletoe-free stands at age 20 to growing stock level[6] 80 (GSL–80),

3. P + C100 = same as item 2, plus subsequent low thinning at 30-year intervals to GSL–100,

4. P + C120 = same as item 2, plus subsequent low thinning at 30-year intervals to GSL–120, and

5. DMT = dwarf mistletoe control thinning, either at age 20 or 50, of dwarf mistletoe-infested stands. This type of thinning will be discussed in more detail, later in this section.

Results

Tables 2 through 6 show differences in stand development effects among the different initial stand densities for a given prescription, and among prescriptions for a given stand density. To allow better comparison of the position and depth of the dominant canopy as well as of canopy coverage, values from tables 3 through 6 are graphically displayed in figures 4 through 7 for stand densities at age 20 years, of 1,000, 2,000, 4,000, and 8,000 trees per acre, respectively. A graph was not developed for table 2 (500 trees per acre) because most prescriptions were not applicable to this low initial stand density.

In figures 4 through 7, the dashed lines indicate the average crown length and position of dominant trees in the stand for prescriptions resulting in canopy cover of less than 100 percent, as determined by values of less than 100 for Crown Competition Factor (CCF) (Krajicek and others 1961; Alexander and others 1967). The solid lines indicate crown length and position when CCF values are greater than 100, hence canopy coverage exceeds 100 percent. Although CCF cannot serve as a continuous scale measure of crown closure (Krajicek and others 1961), it can indicate the point of 100 percent canopy coverage. This occurs at a CCF value of 100. At higher values of CCF, the stand has complete canopy coverage—but how much more than 100 percent cannot be determined from the CCF value. Similarly, at values less than CCF 100, we know the stand has less than 100 percent of the ground area covered by crowns.

Although figures 4 through 7 distinguish between canopy cover of greater and less than 100 percent, and the current thermal cover definition specifies crown cover of 70 percent or greater, any cover is better than no cover for wintering game (Thomas and others 1979). For this reason, the CCF values calculated in LP STAND GRO are included for each prescription (tables 2 through 6), at each interval of stand development—so as to be available for interpretation by wildlife researchers as an indicator of crown density.

In considering the cover implications of tables 2 through 6 and figures 4 through 7, it is important to remember that the projected stand characteristics are for typically even-aged, single-storied lodgepole pine stands on lands having 100-year site indexes of about 60 ft. Projections for different quality sites indicate differences in crown development, particularly in attained heights.

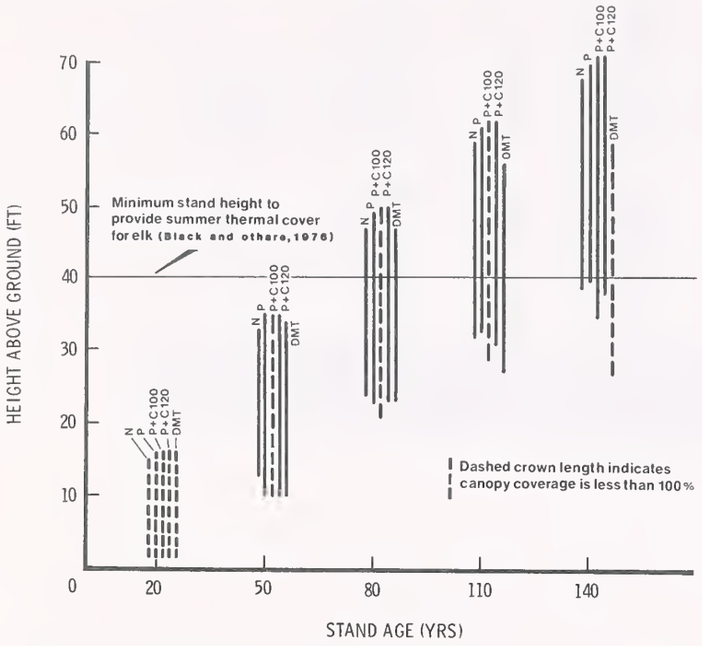

Figure 4.—Development of height, depth, and position of the dominant canopy—in thinned and unthinned stands: initial stocking, age 20 years = 1,000 trees per acre (see table 3).

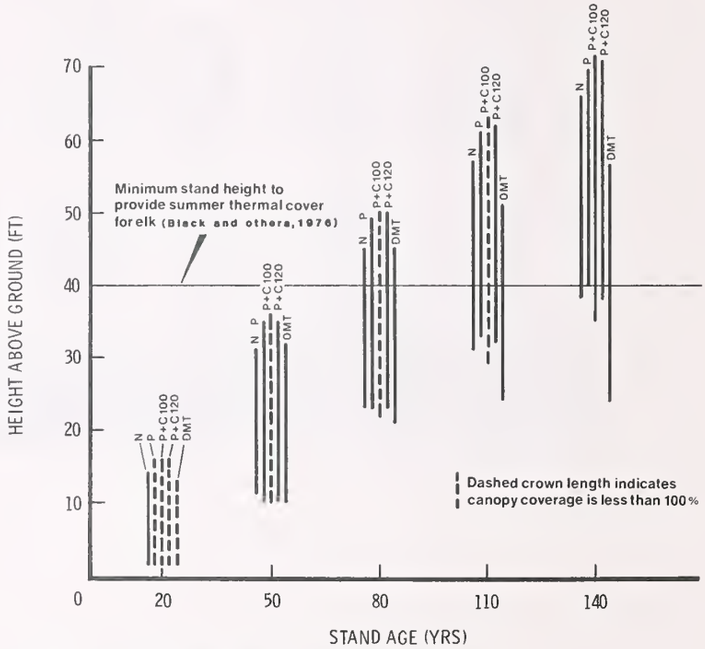

Figure 5.—Development of height, depth, and position of the dominant canopy—in thinned and unthinned stands: initial stocking, age 20 years = 2,000 trees per acre (see table 4).

[5]Low thinning—a method of thinning in which trees of the lowest crown classes are killed first (usually by cutting); with removal of trees of successively higher crown classes, until the desired severity of thinning is attained.

[6]Growing stock level (GSL)—a numerical growing stock index, representing the expected basal area of the subject stand when the tree of average basal area reaches 10 inches d.b.h. (Myers 1967). It is useful for indicating stand density both before and after thinning; hence it is used as an indication of thinning severity.

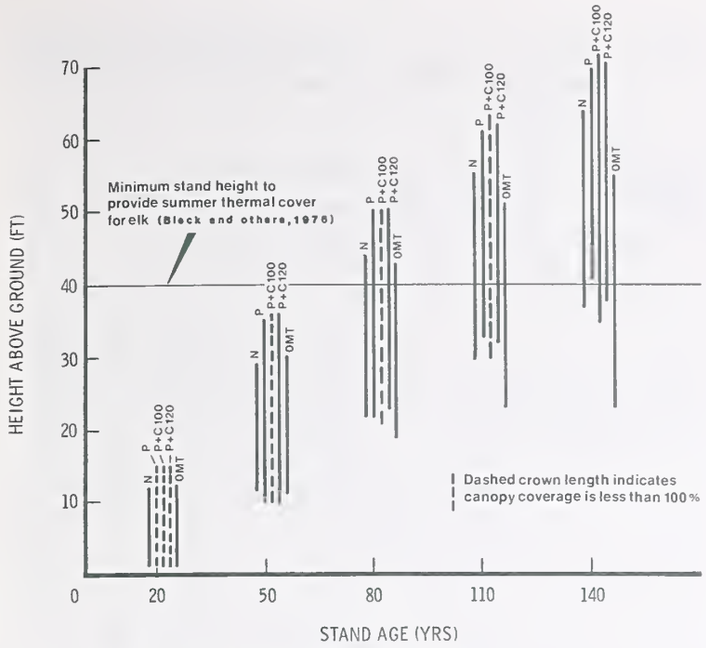

Figure 6.—Development of height, depth, and position of the dominant canopy—in thinned and unthinned stands: initial stocking, age 20 years = 4,000 trees per acre (see table 5).

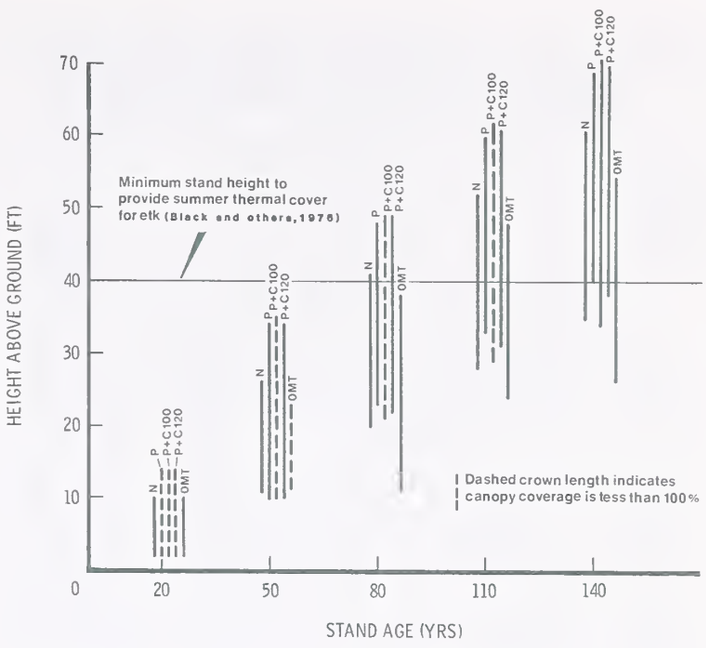

Figure 7.—Development of height, depth, and position of the dominant canopy—in thinned and unthinned stands: initial stocking, age 20 years = 8,000 trees per acre (see table 6).

Heights of dominant lodgepole pine trees increase with age and site index, but are suppressed by higher stand densities. This is illustrated in tables 7 and 8 where CCF 125 represents moderate stand density and CCF 400 represents high stand density (Alexander and others 1967). The boundary line in each table separates the age and site index classes which do and do not provide the minimum height (40 ft) for satisfactory summer thermal cover for mule deer and elk—as currently defined. A general indication of how stand density and thinning in lodgepole pine might influence this thermal cover factor is seen in comparing the ages when the stand reaches the 40-ft threshold, for the different stand density (CCF) levels represented by the two tables.

A more comprehensive indication of thinning effects on stand height as well as on other canopy characteristics is shown in figures 4 through 7, where four different initial stocking levels are illustrated. A comparison of natural stand development among the different stocking levels at each of the given ages shows, again, that height and crown length are reduced with increasing stand density. The effect of thinning on crown development can be seen in each of the figures, by comparing the various thinning prescriptions with the no-thinning situation. It is noteworthy that the thinning prescription resulting in greatest attained height and depth of the canopy (P + C100), accomplishes this at the expense of less than 100 percent canopy coverage (as shown by the dashed line in the figures).

Among thinning prescriptions, however, there do not appear to be large differences in canopy development—with the exception of the dwarf mistletoe thinning (DMT) prescription, where stand height and height to canopy are both reduced.

Dwarf mistletoe (*Arceuthobium americanum*) infection in lodgepole pine reduces tree growth, especially height (Hawksworth and Hinds 1964). Myers and others (1971) indicate this effect in unmanaged stands, over a rotation, can result in a 10 to 30 percent reduction in stand height—depending on time and severity of the infection. An indication of the canopy effects of management response to this serious disease of lodgepole pine is shown by prescription DMT in tables 2 through 6 and figures 4 through 7. Prescription DMT is a dwarf mistletoe control thinning (Myers and others 1971) that removes varying numbers of large and small trees in the stand, depending on stand density and the history of stand infection. With the exception of high initial stocking levels (fig. 7), where attained heights of dominants are kept from reaching the 40-foot threshold until past 80 years of age, the DMT treatments appear to maintain canopy coverage and depth about as well as any of the other management prescriptions compared. However, the consistently lower position of the canopy, of stands receiving mistletoe control thinning, is evident in the graphs (fig. 4 through 7). How canopy position effects thermal qualities of lodgepole pine canopies and wildlife must be resolved by specific studies.

Table 7.— Heights of dominant trees at CCF levels of 125 or less for site index classes 30 to 100 by decadal ages 30 to 140 years[1]

Total age (years)	Site index class							
	30	40	50	60	70	80	90	100
	Height in feet							
30	16	20	24	28	32	36	40	45
40	18	23	28	34	39	44	49	55
50	20	26	32	39	45	51	58	64
60	22	29	36	44	51	58	65	72
70	24	32	40	48	56	64	72	80
80	26	35	44	52	61	70	79	88
90	28	37	47	56	66	75	85	94
100	30	40	50	60	70	80	90	100
110	32	42	52	63	73	84	94	104
120	34	44	55	66	76	87	98	108
130	35	46	57	68	79	90	101	111
140	37	48	59	70	81	92	103	114

[1]From Alexander and others 1967.

Table 8.— Heights of dominant trees at CCF 400 for site index classes 30 to 100 by decadal ages 30 to 140 years[1]

Total age (years)	Site index class							
	30	40	50	60	70	80	90	100
	Height in feet							
30	9	11	13	15	17	18	20	22
40	11	14	17	20	23	26	29	32
50	13	17	21	25	29	33	37	41
60	15	20	25	30	35	40	45	50
70	17	23	29	35	40	46	52	58
80	19	26	32	39	45	52	59	65
90	21	28	36	43	50	57	64	72
100	23	31	39	46	54	62	70	77
110	25	33	41	49	57	66	74	82
120	27	35	44	52	60	69	77	86
130	28	37	46	54	63	72	80	89
140	30	39	48	56	65	74	83	92

[1]From Alexander and others 1967.

Conclusions

In total, these stand projections suggest that low thinnings of overstocked even-aged lodgepole pine stands will not result in long-term impairment of the vertical dimension of thermal cover (as currently defined). Such thinnings might even provide and maintain it better. However, this possibility needs to be weighed against the potential for reducing crown coverage too much with some thinnings. These questions need to be resolved by wildlife studies designed to observe the extent and duration of possible offsetting factors occurring in thinned stands.

The situation of uneven-aged and multistoried lodgepole pine stands, such as resulting from cyclic mountain pine beetle (*Dendroctonus ponderosae* Hopk.) infestations of mature and overmature stands obviously involves different cover implications than those discussed. When the changes in stand structure wrought by periodic mountain pine beetle infestations can be reliably incorporated in LP STAND GRO, this factor can also be considered in examining different silvicultural options for managing canopy characteristics of lodgepole pine.

All of the effects discussed here should be of interest to wildlife researchers and forest managers. Other stand development effects included in tables 2 through 6 are average stand diameters by basal areas, and merchantable volumes. These indications of tree size and yield are important to timber planners and managers interested in examining the amount and value of timber yields that are associated with management prescriptions being considered for wildlife cover enhancement.

PUBLICATIONS CITED

Alexander, R. A.; Tackle, D.; Dahms, W. Site indexes for lodgepole pine with corrections for stand density: methodology. Res. Pap. RM-29. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1967. 18 p.

Beall, R. C. Elk habitat selection in relation to thermal radiation. In: Heib, Susan R., ed. Proceedings, elk-logging-roads symposium; 1975 December 16–17; Moscow, ID. Moscow, ID: University of Idaho; 1976: 97–100.

Black, H.; Scherzinger, R.; Thomas, J. W. Relationships of Rocky Mountain elk and Rocky Mountain mule deer habitat to timber management in the Blue Mountains of Oregon and Washington. In: Heib, Susan R., ed. Proceedings, elk-logging-roads symposium; 1975 December 16–17; Moscow, ID. Moscow, ID: University of Idaho; 1976: 11–31.

Cole, D. M. A cubic-foot stand volume equation for lodgepole pine in Montana and Idaho. Res. Note INT-150. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1971. 8 p.

Cole, D. M.; Jensen, C. E. Models for describing vertical crown development of lodgepole pine stands. Res. Pap. INT-292. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 10 p.

Cole, D. M.; Stage, A. R. Estimating future diameters of lodgepole pine trees. Res. Pap. INT-131. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 20 p.

Edminster, C. B. RMYLD: computations of yield tables for even-aged and two-storied stands. Res. Pap. RM-199. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1978. 20 p.

Gary, H. L. Crown structure and distribution of biomass in a lodgepole pine stand. Res. Pap. RM-165. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1976. 20 p.

Hawksworth, F.; Hinds, T. E. Effects of dwarfmistletoe on immature lodgepole pine stands in Colorado. J. For. 62: 27-32; 1964.

Krajicek, J. E.; Brinkman, K.; Gingrich, S. Crown competition—a measure of density. For. Sci. 7(1): 35–42; 1961.

Myers, C. A. Yield tables for managed stands of lodgepole pine in Colorado and Wyoming. Res. Pap. RM-26. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1967. 20 p.

Myers, C. A.; Hawksworth, F.; Stewart, J. Simulating yields of dwarf mistletoe-infested lodgepole pine stands. Res. Pap. RM-72. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1971. 15 p.

Reifsnyder, W.; Lull, H. Radiant energy in relation to forests. Tech. Bull. 1344. Washington, DC: U.S. Department of Agriculture, Forest Service; 1965. 111 p.

Stage, A. R. Prognosis model for stand development. Res. Pap. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 32 p.

Stage, A. R. Prediction of height increment for models of forest growth. Res. Pap. INT-164. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1975. 20 p.

Thomas, J. W.; Black, H.; Scherzinger, R.; Pedersen, R. Deer and elk. In: Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Agric. Handb. 553. Washington, DC: U.S. Department of Agriculture, Forest Service; 1979: 104–127.

U.S. Department of Agriculture, Forest Service. Forest Statistics for the United States, by State and region, 1970. Washington, D.C.: U.S. Department of Agriculture, Forest Service; 1972. 96 p.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1983-0-676-032/41

Cole, Dennis M. Canopy development in lodgepole pine: implications for wildlife studies and multiple resource management. Gen. Tech. Rep. INT-139. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 13 p.

Describes the use of lodgepole pine crown development models with computerized stand projection programs for examining the effects of alternative timber management prescriptions on canopy characteristics important to wildlife. Instructions are given for exploiting existing data bases with the crown models; and for using the models and procedures to test and refine current forest wildlife cover concepts.

KEYWORDS: canopy development, wildlife cover, thermal cover, canopy characteristics, lodgepole pine, *Pinus contorta*

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)